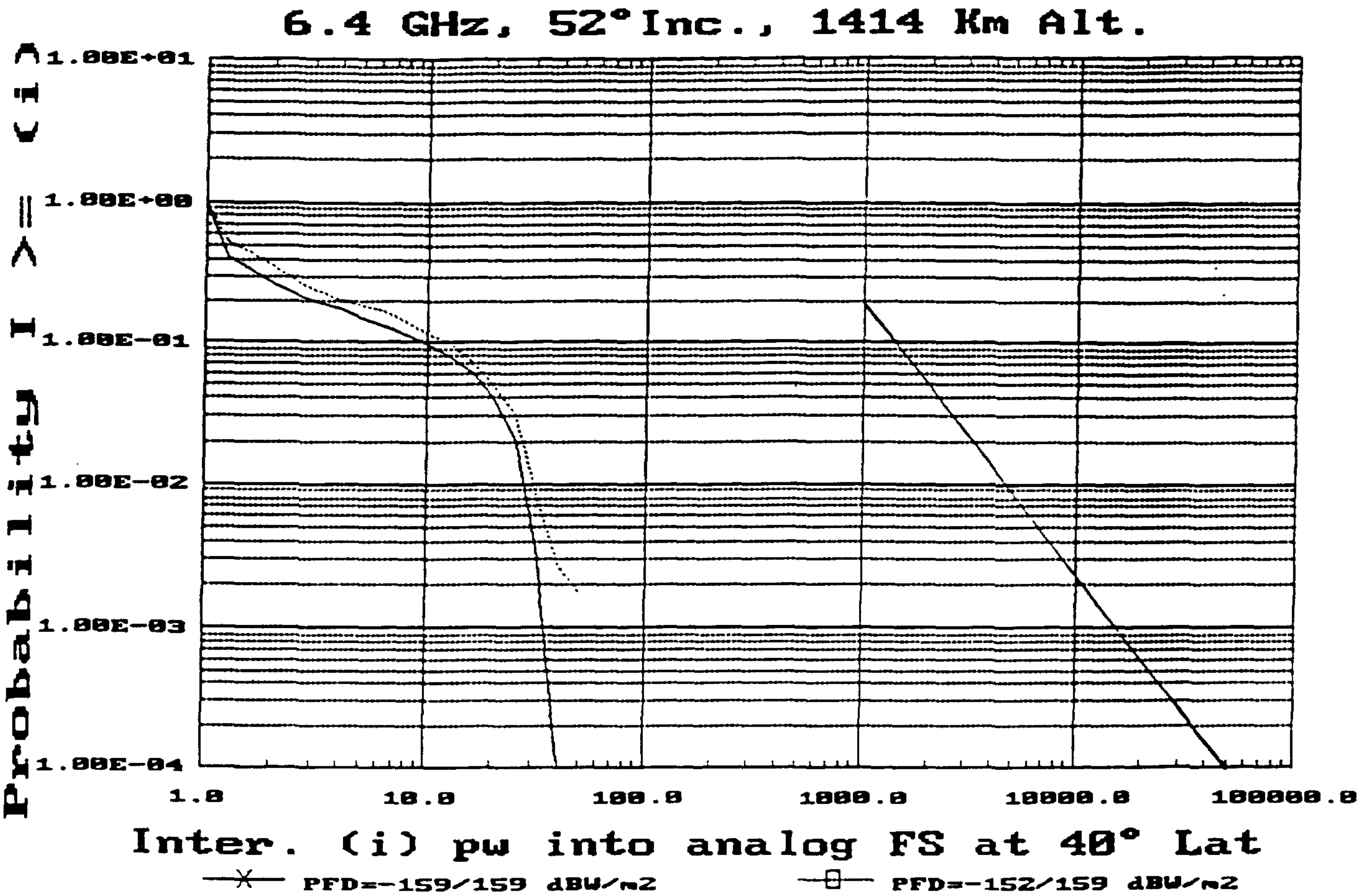
Figure A-1
Probability of Interference vs Interference (pW)
from GLOBLASTAR Feeder Downlink to 50-Hop Analogue Microwave System



The second, more detailed, analysis considers terrestrial systems that are currently in existence and utilizes their actual parameters and pointing angles. Industry specified C/I values are utilized in evaluating the interference situation from GLOBALSTAR feeder links that are operating in a co-frequency mode. The analysis also assumes that the GLOBALSTAR satellites are actually illuminating the main lobe of the terrestrial system antenna. No time-variant characteristics of the GLOBALSTAR constellation, or realistic azimuthal discriminations are assumed. Therefore, the analysis results in interference estimates that are extremely conservative. Attachment 10 gives the details of the analysis and results. Key results are discussed below.

3.3.2.4 Results of Analysis of GLOBALSTAR Feeder Link Compatibility with Terrestrial Services

Downlink

OFS-6525 - 6875 MHz Band

The total number of cases analyzed represent about 10 percent of approximately 19,000 licensed receivers operating in the U.S. in the 6525-6875 MHz band. The selected areas (all of the analyzed receivers are located in congested areas as defined by the FCC in Report DC-1950, September 23, 1991) contain enough microwave links to be a representative sample. Most of the analyzed cases had main beam coupling with the satellite, and the analyses were conducted based upon worst case interference scenarios.

Of the approximately 2000 cases analyzed, only 2% showed that the interference objective is met within 3 dB. Over 85% of the cases show significant margin. There were about 550 digital cases in the sample, out of which there were 157 cases which fell within a narrow range of acceptable interference value (C/I), others showed significant margins.

The sample of 2000 cases analyzed is about 10% of the total number of channels in operation. The analysis shows high potential for sharing if appropriate coordination procedures are adopted. Additional analyses including simulations with LEO constellation parameters and incorporating time-variant statistics and azimuthal discrimination will reduce actual expected interference potential and durations of interference.

Auxiliary Broadcast-6875 - 7125 MHz Band

The point-to-point terrestrial fixed FM/Video utilization of this band in the U.S. allows using an easy-to-meet interference objective. The long haul 66 dB C/I, medium haul 66 dB C/I, or short haul 56 dB C/I, are low compared to other types of modulation. This criteria was easily met, despite the fact that most of the cases were engaged with main beam coupling with the satellite. The ENG utilization of this band is addressed separately below.

Given similar characteristics of the paths analyzed in the five areas, and the deployment of FM/Video, the ability for sharing the spectrum with MSS feeder links appears promising and is recommended.

Auxiliary Broadcast, Cable Television Relay Service (CARS) - the 12.75-13.25 GHz Band

The sample studied exhibited good potential for MSS feeder links sharing the spectrum. The VSB AM/Video modulation is more susceptible to interference because of the higher needed C/I objective of 61dB, coupled with lower receive carrier levels. Most FM/Video systems are short haul. Long haul systems may have slightly less potential for sharing.

Additional analysis including orbital simulations are needed to determine the duration of interference and the azimuthal discrimination. This can further enhance the sharing potential.

Electronic News Gathering (ENG) or TV Pick-up - 6425-6525 MHz, 6875-7125 MHz and 12-75-13.25 GHz Bands

The studied configurations show little impact from the GLOBALSTAR satellite under even worst case fading conditions. All configurations remain unaffected by interference.

Analysis of the performance under worst case fading conditions should also be complemented with interference duration, the desired carrier's fade duration, and the probability of a simultaneous occurrence. These effects can further improve sharing.

Feeder Uplink Analysis of Sharing with Terrestrial Services

General

The results of the sharing analyses discussed in this report are based on standard procedures followed for geostationary satellites. Coordination with terrestrial services can be further improved by taking advantage of such mitigation techniques as artificial RF shielding, terrain blockage, azimuthal discrimination, etc.

The number of LEO/MSS feeder link stations to be deployed per system on a global basis will be limited. Small countries need only one feeder link station. Larger countries like the U.S. may require more gateways.

It appears that even in non-congested areas many of the standard interference mitigation methods effective in clearing a proposed feeder link site may need to be employed.

The standard methods that may be followed include:

1. Reducing transmission power density in a portion of the spectrum; for example in the 6525 to 6875 MHz band.

2. Utilizing actual path blockage provided by man-made obstacles to increase the path losses between the feeder link station and the terrestrial station.

3. Conduct on-site RFI measurements to determine actual RFI environment and also to indicate what additional corrective steps are necessary.

4. Construct a shield towards the terrestrial facilities, if necessary.

5. Change or upgrade the terrestrial antennas to reduce the cases to acceptable levels.

6. Relocate the proposed feeder link site in another area to assure interference free operation by taking advantage of terrain features.

The location of a feeder link in congested areas may require several iterations of the mitigation techniques with field surveys and RFI measurement to locate a viable site.

4500-4800 MHz Band

There is considerable flexibility in locating the gateway stations. One can site the stations away from the congested areas, if required, and at reasonable distances from military installations to facilitate coordination with military systems. Sufficient information is not available on the military systems to draw definitive conclusions. The FSS sharing situation, based on RBW, looks feasible as discussed in other documents. Effort should be made to explore whether a small number of LEO/MSS gateway stations can coexist with fixed and mobile military systems. According to the recent NTIA spectrum utilization study (NTIA/ITS Report: "A Preliminary Look at Spectrum Requirements for the Fixed Service, dated May, 1993), there were a total of 1,738 total assignments in this band 4400-4990 MHz. Sharing with LEO/MSS uplinks may be made possible with careful siting and frequency coordination, in a 200 MHz segment of the 4400-4990 MHz band (in the 4600-4800 MHz segment).

5000-5250 MHz Band

Sharing with aeronautical radionavigation, and aeronautical mobile has not been explicitly analyzed in this document. Work is in progress. There is considerable potential in expanding the RDSS feeder link authorization by increasing the bandwidth and by including RBW. The MLS use has been limited on a worldwide basis. LQP feels that there is a great potential in obtaining worldwide agreement for use of this band for LEO/MSS feeder links. It should be technically feasible to coordinate the small number of LEO/MSS gateway stations. Global allocation for LEO/MSS feeder link uplinks is recommended in this band.

6525 - 6875 MHz Band

Based on the results of the analysis in the 6 GHz OFS band, it appears that, as long as coordination is used to avoid conflicts with existing users, LEO feeder uplinks should be able to share the spectrum.

Analysis of Sharing Between Feeder Uplink and Terrestrial Systems
10.7 - 10.95 and 11.20 - 11.45 GHz Bands

Based on the results of the analysis in the 11 GHz band, spectrum sharing between a LEO feeder link and the terrestrial fixed users is possible.

The analysis for the site in Rapid City, South Dakota indicates that there was no interference predicted after the terrain features and the over-the-horizon losses were included. Spectrum sharing appears possible in this environment.

Based on the analysis performed for an uplink site at Staten Island, New York, which is a congested area, there appears to be only one major case that needs to be resolved to allow transmission between 10.7 and 10.95 GHz and only one major case that needs to be resolved to transmit in the 11.2 to 11.45 GHz band.

Radio frequency measurements and path surveys are required in an effort to resolve any conflicts. Regardless of what steps are required to fine tune the results, it appears that sites near major metropolitan areas may be viable candidates for locating MSS feeder link uplinks in the 10.7 to 11.45 GHz band.

However, locating a site in a non-congested area is recommended as the number of cases encountered in a congested area is much larger.

3.3.3 Issues Associated With Ka-Band Feeder Links

LQP strongly prefers not to use the 18-30 GHz frequency band for the GLOBALSTAR feeder links. Coordination of frequencies with other MSS satellite services will be difficult as stated before. LQP also agrees with the Commission that

"LMDS transmissions, however, would cause unacceptable interference into MSS feeder link operations." Attachment 11 discusses these issues in more detail. Furthermore, the usage of Ka-band for feeder links may preclude FSS Systems such as Teledesic.

3.3.3.1 Cost

In addition to significant increase in space segment costs, ground segment costs would also be escalated dramatically by the need for larger (to overcome rain attenuation) and higher precision antennas, and high powered 20 or 30 GHz transmitters for the ground stations which may not be available.

The number of Gateway stations planned by GLOBALSTAR may be over 200 worldwide. This presumes that LQP will not be forced to employ diversity sites for rain attenuation, which would most certainly be required at Ka-band, increasing the total quantity of antennas by about 50%. This would be very costly, resulting in higher rates to the system users, and decreases public benefit.

3.3.3.2 Coordination

It will be very difficult, if not impossible, to coordinate frequencies and ground station locations if all five LEO/MSS systems use Ka-band feeder links. In addition, as mentioned above, coordination with LMDS could be very difficult, and indeed impossible for some locations where system requirements necessitate a ground station for GLOBALSTAR.

ATTACHMENTS

No.	Description
1	"Assessment of MES-induced RFI on Hybrid GPS/GLONASS Aviation Receivers," April 29, 1994, Sat Tech Systems
2	"Simulation of Interference into Analog Radio-Rely Routes from Low-Earth Orbiting Satellites of the LEO D Mobile-Satellite Service Systems," ITU-R document 2-2/27-E, 25 January 1994
3	"Field Measurements of ITFS Interference in the San Francisco Bay Area," April 1994
4	"Field Measurements of ISM Interference in the San Francisco Bay Area," April 1994
5	"Discussions of ISM Measurements in the San Francisco Bay Area," April, 1994
6	Excerpts from CEPT Project Team SE 18, Final Report, "Frequency Sharing Implications of Feeder-Links for Non-GSO MSS Networks in FSS Bands," February 1994
7	"Reverse Band Working of NGSO/MSS Feeder Links in the 4.5-4.8 GHz and 6.075-7.025 GHz Allotment Bands, Document USTG 4/5-8, April 27, 1994
8	"Feasibility of Sharing FSS Allocations in Reverse-Band Working Mode for Non-GSO MSS Satellite Feeder links, " Document USTG 4/5-5(Rev.1), April 29, 1994
9	"FSS Earth Station to MSS Land Earth Station (LES) Coordination Distances in Reverse Band Working" (RBW) Mode, Document USTG 4/5-4, April 29, 1994
10	RTCA Digest No. 98, ISSN No. 0193-4422, January-March, 1994
11	"Why Ka-Band is Unsuitable for Accommodating the Feeder links of all Proposed LEO/MSS Systems," May 2, 1994
12	"Coordination of LEO Satellites with Terrestrial Users," April 1994, Comsearch

Engineering Certification

I hereby certify that I am the technically qualified person responsible for the preparation of the engineering information in this Technical Appendix, that I am familiar with Parts 2 and 25 of the Commission's Rules, and its proposed rules and policies in the Notice of Proposed Rule Making in CC Docket No. 92-166 (FCC 94-11), and that I have either prepared or directed the preparation of the engineering information contained in this Technical Appendix, and that it is complete and accurate to the best of my knowledge.

By:

Robert A. Wiedeman
Vice President of Engineering
Loral/QUALCOMM Partnership, L.P.

CALIFORNIA ALL-PURPOSE ACKNOWLEDGMENT No. 5193

State of California
County of Santa Clara

On 05-03-94 (DATE) before me, Marie Ann Whiteside, Notary Public (NAME, TITLE OF OFFICER - E.G., "JANE DOE, NOTARY PUBLIC"),

personally appeared Robert A. Wiedeman (NAME(S) OF SIGNER(S)),

☐ personally known to me - **OR** - ☒ proved to me on the basis of satisfactory evidence to be the person(~~s~~) whose name(~~s~~) is ~~are~~ subscribed to the within instrument and acknowledged to ~~me that~~ he ~~she/they~~ executed the same in his ~~her/their~~ authorized capacity(~~ies~~), and that by his ~~her/their~~ signature(~~s~~) on the instrument the person(~~s~~), or the entity upon behalf of which the person(~~s~~) acted, executed the instrument.

OFFICIAL SEAL
Marie Ann Whiteside
NOTARY PUBLIC - CALIFORNIA
SANTA CLARA COUNTY
My Comm. Expires Dec. 12, 1994

WITNESS my hand and official seal.

Marie Ann Whiteside
SIGNATURE OF NOTARY

OPTIONAL SECTION

CAPACITY CLAIMED BY SIGNER

Though statute does not require the Notary to fill in the data below, doing so may prove invaluable to persons relying on the document.

- ☒ INDIVIDUAL
- ☐ CORPORATE OFFICER(S)
  TITLE(S)
- ☐ PARTNER(S) ☐ LIMITED ☐ GENERAL
- ☐ ATTORNEY-IN-FACT
- ☐ TRUSTEE(S)
- ☐ GUARDIAN/CONSERVATOR
- ☐ OTHER:

SIGNER IS REPRESENTING:
NAME OF PERSON(S) OR ENTITY(IES)

OPTIONAL SECTION

THIS CERTIFICATE MUST BE ATTACHED TO THE DOCUMENT DESCRIBED AT RIGHT:

Though the data requested here is not required by law, it could prevent fraudulent reattachment of this form.

TITLE OR TYPE OF DOCUMENT Engineering Certification

NUMBER OF PAGES 1 DATE OF DOCUMENT 5-3-94

SIGNER(S) OTHER THAN NAMED ABOVE n/a

ATTACHMENT 1

Assessment of MES-Induced RFI On Hybrid GPS/GLONASS Aviation Receivers

Prepared for:

Globalstar
Loral Qualcomm Satellite Service, Inc.
3825 Fabian Way, Palo Alto, CA. 94303

April 29, 1994

By:

Sat Tech Systems, Inc.
2775 So. Quincy Street, Arlington, VA. 22206-2241

Assessment of MES-Induced RFI on Hybrid GPS/GLONASS Aviation Receivers

Table of Contents

Assesment of MES-Induced RFI On Hybrid GPS/GLONASS Aviation Receivers

List of Exhibits

Assessment of MES-Induced RFI on Hybrid GPS/GLONASS Aviation Receivers

Section 1
Introduction and Problem Statement

1.1 Introduction

This report assesses the impact of ground-based Globalstar Mobile Earth Station (MES) out-of-band radio frequency emissions on aviation Global Navigation Satellite Service (GNSS) receivers using GPS and GLONASS signals.

GNSS receivers determine a solution for current user position and time by processing (typically) four or more ranging signals transmitted by GPS and GLONASS spacecraft (and other spacecraft in the future). In this report, the term "GNSS spacecraft" will be used generically to refer to some combination of GPS, GLONASS and other spacecraft transmitting ranging signals intended to support these receivers. The number of signals actually received and tracked by a receiver, at any instant of time, is a random variable that depends on geographic location, time of day, health status of the potentially-available spacecraft, blockage and masking effects, receiver operating parameters and software, and other factors including potential radio frequency interference as discussed in this report.

GNSS receivers intended for the aviation market satisfy ARINC Characteristic 743A and FAA Technical Standard Order (TSO) C-129, which specify receiver functionality and performance. These receivers will incorporate altitude aiding from inertial or pressure instruments in addition to measurements of ranging signals from the GNSS satellites. Clock coasting may also be employed. Aviation receivers are intended for use on platforms whose orientation and attitude is constantly changing; this can lead to signal blockage and loss of tracking due to shadowing from tail surfaces, wings and even the fuselage (in extreme maneuvers). As a result, the receivers are designed to tolerate the loss of individual and multiple signals for short periods of time. A key issue in this analysis is the metric used to measure GNSS receiver performance impairment.

As noted above, the number of signals actually tracked by a GNSS receiver will vary over time even in the absence of RFI. This is completely normal and expected. From an operational perspective, a pilot will consider the receiver to be operating normally if it can a) generate a position solution that has high integrity or confidence and b) satisfies the horizontal and vertical accuracy requirements for the phase of flight being flown and for which the receiver is intended to provide support. Occasional outages are tolerable as long as they are clearly annunciated to the pilot.

The International Civil Aviation Organization's (ICAO) Review of the General Concept of Separation Panel (RGCSP), and All Weather Operations Panel (AWOP) are currently defining specifications for Required Navigation Performance (RNP) in terms of accuracy. The FAA is also working to define RNP, with requirements framed in terms of accuracy, availability, integrity and continuity of function. Exhibit 1-1 shows the nominal RNP parameters vs. phase of flight as contained in the DOT/DoD **Federal Radionavigation Plan** and a number of other relevant documents. For this assessment of the Globalstar MES impact on aviation GNSS receivers, the measure of impairment will be a threshold function related to these RNP parameters. If a receiver can fulfill these RNP specifications in an environment containing Globalstar MESs, the navigation

Exhibit 1-1. Nominal RNP Parameters vs. Phase of Flight

RNP Parameter	Phase of Flight				
	Oceanic	Domestic	Terminal	NPA	Cat I
Current Route width [8]	60 nmi	8 nmi [3]	4 nmi	N/A	N/A
System use accuracy	12.6 nmi [1]	1.9 nmi	1.0 nmi	0.1 nmi	110 feet; Horizontal 33 feet; Vertical
Sensor accuracy (one-sided error bound, 95%)	3.8 nmi [2] 0.124 nmi [5] 1.0 nmi [4]	1000m 0.124 nmi [5] 1.0 nmi [4]	500 m 0.124 nmi [5]	100 m [1] 0.056 nmi [5]	5.6m vertical [6] 7.0 m vertical [7]
Availability	0.99999	0.99999	0.99999	0.99999	0.98 (GND H/W) [6] 0.999 [7]
Integrity	120 sec. time to alarm	60 sec. time to alarm	30 sec. time to alarm	0.3 nmi; 10 sec. time to alarm	110 ft. (vert.) 6 sec. time to alarm
Continuity of function	>1 - (1.9 x 10^{-4}) per 3.5 hr. flt. leg [4] >10^{-8}/hr [7; Nav] >10^{-5}/hr [7; integrity]	>1 - (4 x 10^{-5}) >10^{-8}/hr [7; Nav] >10^{-5}/hr [7; integrity]	>1 - (8 x 10^{-5}) per 30 minutes >10^{-8}/hr [7; Nav] >10^{-5}/hr [7; integrity]	>1 - 10^{-4} (TBR) per 150 sec. approach >10^{-8}/hr [7; Nav] >10^{-5}/hr [7; integrity]	>1 - (6 x 10^{-5}) per 150 sec. approach [6]

[1] Federal Radionavigation Plan (FRP)
[2] RTCA/DO-187, 12 November 1984
[3] Below FL180
[4] Proposed EUROCAE standard
[5] TSO-C129, 10 December 1992
[6] RTCA/DO-217, **MASPS for DIAS: Special Category I**, 27 August 1993
[7] WAAS System Specification (Draft)
[8] Route width is not an RNP parameter; it is provided for comparison purposes only.

SH688

function provided by the receiver will be considered to be unimpaired. If the receiver cannot fulfill these specifications, the navigation function will be considered to be impaired.

1.2 Problem Statement

Given the time-varying nature of nominal GNSS operations, as well as the time-varying nature of potential interference geometries, the impact assessment can actually be understood as three separate problems:

a. What is the likelihood or risk that a Globalstar MES will adversely affect the reception of GNSS satellite signals on an aircraft equipped with a GNSS receiver?

b. Given that signal reception is adversely affected under specified conditions, what is the operational impact on the affected aircraft's navigation function?

c. Does the potential for adverse impact on signal reception or navigation function imply a policy imperative?

1.3 Report Organization

Section 2 provides assumptions and groundrules for analysis. Section 3 presents a link budget for GPS and GLONASS signals. Section 4 assesses impact on user navigation performance. Section 5 presents a summary and conclusions. Appendices A, B and C present additional data on the impact of GNSS receiver algorithms that generate independent GPS and GLONASS solutions (A), the impact of bad uploads on the GNSS satellites (B), and potential RFI mitigation techniques(C). Appendix D provides additional information on the link margin assessment for GLONASS using the MathCad software.

Section 2
Assumptions and Ground Rules

2.1 Globalstar MES Characteristics.

Under typical operating conditions, the Globalstar MES will generate a time-gated CDMA spread spectrum signal with a nominal bandwidth of 1.23 MHz and nominal inband power of approximately 0.3 Watts (24 dBm) when actively transmitting. This power level is nominal for beams near the edge of coverage; MES transmit power levels are commanded from the Globalstar gateway terminal, and can be reduced somewhat for inner beams. Under shadowed conditions, the transmit power level can be increased to 3 Watts (34 dBm). The duty cycle for voice operations is typically 40%, with a frame of 20 msec driven by the voice codec. The out-of-band emissions of the MES are dominated by intermodulation (IM) products at small frequency offsets and broadband noise at larger frequency offsets. Exhibit 2-1 illustrates the spectrum that will be used for this analysis.

2.2 GNSS Signal Characteristics and Spectrum Occupancy.

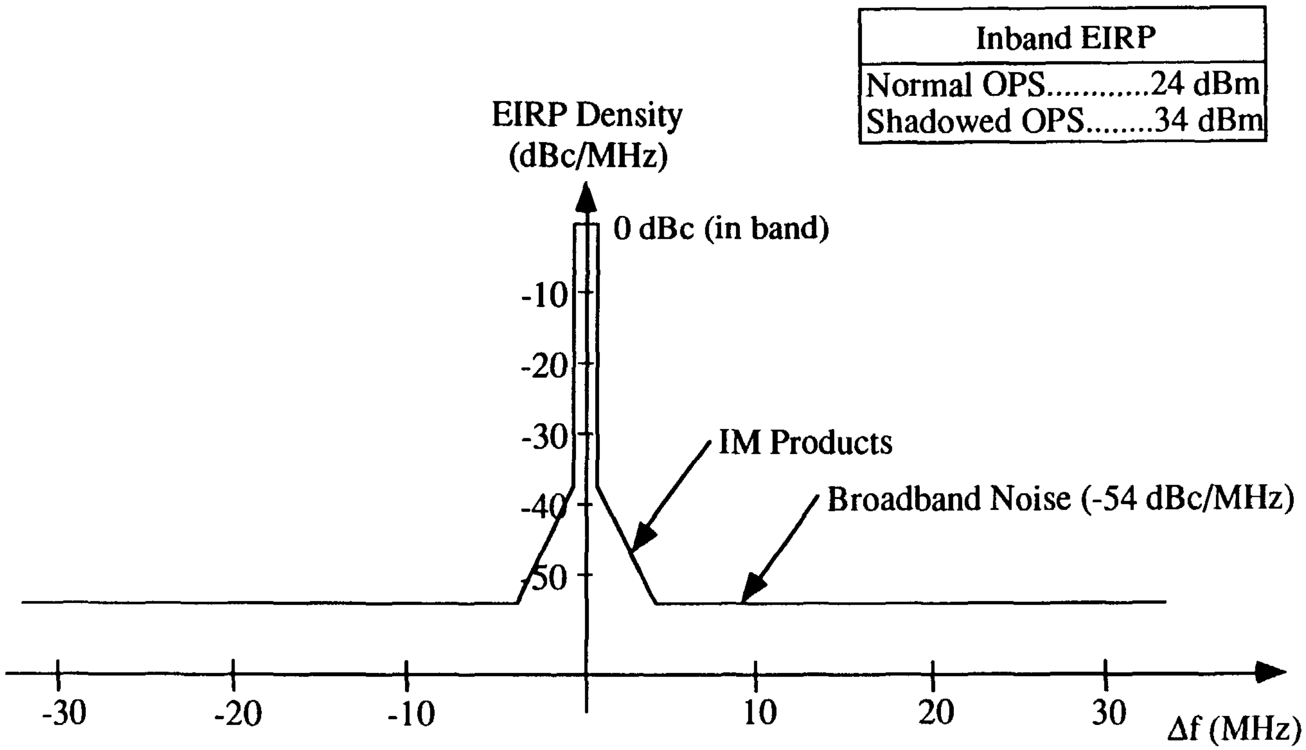
The GPS L1 center frequency is 1575.42 MHz; the signal is biphase modulated with data at 50 bps and a Code Division Multiple Access (CDMA) cover sequence at 1.023 Mcps (for the coarse/acquisition (C/A) code supporting the Standard Positioning Service (SPS), which is authorized for civil use), giving rise to a two-sided transmission spectrum of roughly 2 MHz. The minimum specified signal level at the Earth's surface is -130 dBm per signal[1], although in practice the signal strength is typically somewhat higher. Due to the spread spectrum nature of the GPS waveform, narrowband interfering signals are spread out in frequency as the GPS signals are despread prior to tracking. Wideband or noiselike signals retain their broadband nature. This allows a GNSS receiver to withstand radio frequency interference (RFI) that exceeds the GPS signal level measured at the GNSS receiver input. Based on ARINC characteristic 743A-1, a GNSS receiver will process GPS signals normally if the ratio of power levels between the interfering signal and the desired signal, the J/S ratio, is 24 dB or less (for interfering signals with bandwidths $\geq$ 100 kHz).

GLONASS relies on Frequency Division Multiple Access (FDMA) as well as CDMA. The GLONASS channels are identified by channel IDs 0 through 24, located on 562.5 kHz centers from 1602 MHz to 1615.5 MHz; each signal is pseudonoise (PN) spread with a 511 kcps CDMA cover, leading to a set of overlapping spectra with individual two-sided bandwidths of roughly 1 MHz. GLONASS transmissions are potentially slightly weaker than GPS; the minimum specified signal level at the Earth's surface is -135.5 dBm for GLONASS. The GLONASS frequency plan currently overlaps portions of the radio spectrum assigned to radio astronomy and the Mobile Satellite Service. To resolve this issue, a commitment has been made by the GLONASS Federation to vacate the upper end of its current band. Two alternate frequency plans are relevant.

The first frequency plan would employ a so-called antipodal scheme to assign the lower twelve frequencies twice, relying on the fact that satellites 180 degrees apart in an orbital plane would never be simultaneously visible from any single point on the Earth's surface. The second plan would implement antipodal assignments, and also move the lower edge of the bank of frequencies down to 1598.625 MHz (under this scheme, channel assignments could be identified as -6 to 6).

1. Global Positioning System Standard Positioning Service Signal Specification, December 8, 1993.

Exhibit 2-1: Projected MES Emission Levels (Normative)



The GLONASS Federation is committed to this concept as a long-term goal; however, the time frame for transition is not currently specified. As with GPS, the spread spectrum nature of GLONASS allows a GNSS receiver to operate in the presence of interfering RF energy. However, the lower chip rate of GLONASS relative to GPS reduces the potential rejection capability. Based on ARINC Characteristic 743A-1, a GNSS receiver will process GLONASS signals normally at a J/S ratio (for GLONASS) of 22 dB.

2.3 Interpretation of GNSS Receiver Interference Rejection Specifications

The ratio of jamming or interfering signal power to desired signal power is called the J/S ratio. Based on ARINC Characteristic 743A-1 (November 8, 1993), an aviation receiver must operate normally in the presence of interfering RF energy that exceeds the received signal power level of the desired GPS or GLONASS signals. For a signal with bandwidth in excess of 100 kHz, the level of excedence is 24 dB for GPS signals and 22 dB for GLONASS signals. These specifications must be interpreted for Globalstar MES emissions, which are not bandlimited but instead represent broadband noise. For this analysis, the two-sided noise bandwidth of the GNSS receiver's correlation process is taken to be twice the inverse of the chip time. For example, the noise bandwidth for GPS is taken as the 2.046 MHz null-to-null bandwidth of the C/A code main lobe. The equivalent noise power is then calculated by integrating the $(\sin(x)/x)^2$ filter characteristic over this bandwidth. For GPS, an equivalent rectangular noise bandwidth would be 924 kHz. For GLONASS, an equivalent rectangular noise bandwidth would be 461 kHz.

2.4 GNSS Receiver Navigation Processing

Two means of combining GPS and GLONASS signal measurements have been investigated and demonstrated by the navigation community: (1) generate separate GPS-only and GLONASS-only navigation solutions, and compare these solutions to improve integrity; and (2) merge all the GPS and GLONASS pseudorange measurements in a single navigation solution with additional degrees of freedom. The first alternative requires an algorithm to compare the two navigation solutions, while the second alternative requires an algorithm to convert pseudoranges determined in the SGS coordinate frame to the equivalent pseudoranges in the WGS coordinate frame and a means to correlate system time. The Russian federation has stated that this information will be provided as part of the GLONASS navigation message in the future. The second alternative offers significantly better performance in terms of accuracy, integrity and availability with virtually no increase in complexity relative to the first alternative. Given the recent public availability of the needed coordinate transformations, and the GLONASS federation announcement, technical risk associated with the second alternative is essentially zero. This analysis will therefore assume that all pseudoranges are merged in a single navigation solution. Appendix A addresses the case of independent solutions.

2.5 Navigation Performance Requirements and Assumptions

Four phases of flight are considered in this analysis: (1) domestic en route and terminal area (these are actually two different phases of flight, but will be treated together with accuracy requirements driven by terminal area); (2) nonprecision approach; (3) Category I precision approach; and (4) surface operations.

The unaugmented GPS provides sufficient accuracy performance to satisfy supplemental en route, terminal area and non precision approach (NPA) requirements, but augmentations are necessary to satisfy sole means availability and integrity requirements in these phases of flight. Accuracy requirements are dominated by nonprecision approach operations, with the fault-free 95%

horizontal error specified at 100 meters. Historically, sole means navigation systems have been designed to an availability requirement (with integrity) of 0.99999. To achieve this level of availability with integrity, augmentations can include the use of GLONASS satellites or reliance on the FAA's emerging Wide Area Augmentation System (WAAS). Either augmentation alone would satisfy requirements for these phases of flight. For NPA, the Minimum Descent Altitude (MDA) is 250 feet above terrain. At this altitude, the pilot should visually acquire the runway and transition to a visual approach without reliance on electronic navaids of any sort (including GPS/GNSS). The alarm time for NPA operations is 10 seconds; navaid "coasting" on partial guidance is tolerated for up to 5 seconds. At the start of the approach, TSO C-129 requires the avionics to "look ahead" for five minutes to assure the existence of RAIM in the absence of unexpected failures. After this point, however, RAIM can be lost due to unexpected satellite failures or losses of signal. The pilot can "coast," and continue the approach for the remainder of the five-minute look-ahead period, as long as the navigation capability is intact.

For Category I precision approach, the FAA intends to pursue pre-planned enhancements to the WAAS for a public-use system. The draft specification for the WAAS, recently released for industry comment, requires a vertical system use accuracy (i.e., exclusive of flight technical error) of 7 meters. The availability specification is currently undergoing review, but seems likely to settle at 0.999. Integrity is defined roughly as 1 - Pr{hazardously misleading guidance}, and is specified as 0.9999999 (seven 9's) per hour. Some form of local differential augmentation could also provide the needed accuracy as well as integrity. The RTCA has recently released a **Minimum Aviation System Performance Standard (MASPS) for DGNSS Instrument Landing Systems (DIAS)** supporting Special Category I (SCAT-I) precision approach operations[2], which can be used as a baseline for requirements in this area. It should be noted that the MASPS for DIAS: SCAT-I only requires a ground segment hardware availability of 98%.

For surface operations, either a WAAS or a local differential system could provide the necessary enhancements to accuracy and integrity. Requirements for surface operations are not clearly defined at this time. However, the FAA's documented requirement for surface surveillance accuracy via traditional radar systems is 20 feet (95%) with an update rate of 1 Hz. This accuracy level would be sufficient to support Automatic Dependent Surveillance (ADS) on the airport surface, emerging/future automation systems such as Airport Surface Traffic Automation (ASTA) and Airport Movement Area Support System (AMASS), and autonomous navigation on the airport surface in almost all cases (note: very large aircraft may require more precise navigation systems in order to negotiate tight turns onto regulation width taxiways). A differential system (either wide area or local) is clearly needed to achieve 20 foot accuracy. For ADS, the DGPS system must also be married to a communications system in order to provide position reports to the traffic management function in the tower.

Availability requirements for surface navigation are not defined at this time. In the surface domain, availability drives cost/benefit tradeoffs rather than flight safety. It is anticipated that a WAAS capable of supporting Category I precision approach would also meet all requirements to support surface operations.

For the MES/GNSS impact analysis addressed here, the requirements stated above can be summarized as follows:

a. GPS and GLONASS together can be used to satisfy the requirements for sole means navigation down to nonprecision approach (although a WAAS is also planned to be available in the timeframe of Globalstar operations, and would enable sole means

2. RTCA/DO-217. This document specifies the operational, performance and testing requirements for non federally funded systems supporting precision approach operations to Category I minima.

navigation in all phases of flight discussed above without reliance on GLONASS). The analysis will address users reliant on GPS+GLONASS.

b. Some form of differential augmentation is absolutely required to satisfy requirements for Category I precision approach and surface operations. In this environment, users can satisfy all their operational navigation requirements even if GLONASS was completely unavailable. GLONASS may be used but is not required.

Section 3
Link Budget Analysis

This section assesses the potential for Globalstar MES emissions to affect the GNSS signal tracking performance of an aviation GNSS receiver. The link budgets presented in this section include several parameters which can vary over a range of power levels as a function of the operational environment. To resolve this issue, a nominal link budget will be provided, and then modified on probabilistic grounds to account for potentially variable factors.

Section 3.1 addresses the effect of Globalstar MES emissions on GPS signals, and Section 3.2 addresses the effect on GLONASS signals.

3.1 Link budget Analysis Relative to GPS signals

The minimum specified signal strength of a GPS signal at the Earth's surface is -130 dBm. Exhibit 3-1 presents a standard link budget analysis for nominal MES transmissions in unshadowed conditions. The inband EIRP is 24 dBm. Referring to the MES spectrum of Exhibit 2-1, broadband noise dominates at the GPS frequency and is 54 dB down from these inband EIRP levels when averaged over 1 MHz. This noise floor must be converted to an equivalent interfering noise power by integrating over the effective channel filter characteristic represented by the GPS receiver's channel correlator. This is a $(\sin(x)/x)^2$ characteristic, leading to an equivalent rectangular noise bandwidth of 924 kHz.

Space loss is taken at a range of 100m, and the directive gain of the GNSS user antenna in the direction of the MES is taken as -5 dBi (based on the highest specified gain of a GNSS antenna measured at a zero degree elevation angle, as specified in ARINC Characteristic 743A-1). This results in a received carrier power (MES emissions measured at the GNSS receiver) of -112 dBm. As noted earlier in Section 2.2, the minimum specified signal power for GPS is -130 dBm. The effective J/S = 18 dB, which leaves 6 dB margin relative to the J/S threshold of 24 dB.

The nominal link budget represents a good overall assessment of GPS signal robustness. However, several parameters within the link budget are subject to variation. These parameters are listed below along with their estimated ranges of variation; Exhibit 3-2 illustrates these parameters along with hypothesized probability functions that can be used to assess their impact.

a. MES transmit power. When the MES can access a satellite through an "inner beam", it can reduce its transmit power level in order to conserve battery life and reduce co-channel noise in the Globalstar operating band. Alternatively, under shadowed conditions, the MES can boost transmit power by 10 dB relative to the nominal power level used above. When multiple spacecraft are in view (the typical case), the MES will operate through the satellite with the most favorable uplink power budget in order to minimize battery drain. Shadowed conditions are not considered typical or likely in an out-door environment associated with aviation activity, such as an airport. For this parameter, a modified beta probability density function was selected. Note that this function, as well as the functions described below, relate to the ***variable*** portion of the parameter. This is the ***delta*** that needs to be applied to the link budget.

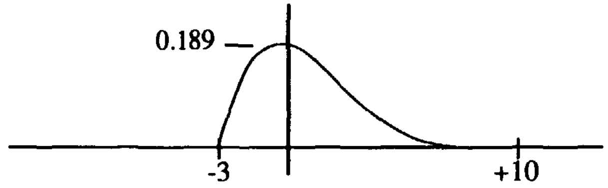
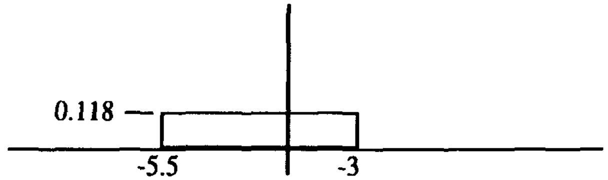
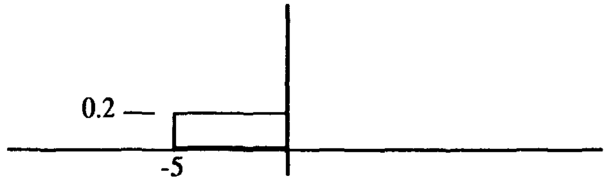
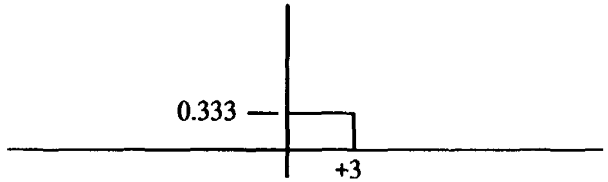
b. GNSS antenna gain toward MES. ARINC Characteristic 743A-1 specifies the range of antenna gain toward the horizon as -7.5 dB to -5 dB (passive antenna), with gain

Exhibit 3-1

Globalstar MES GPS Interference Assessment

Parameter	Value	Units	Notes
Transmitter Power (Total)	24.0	dBm	0.3 Watts nominal power level; BW = 1.23 MHz
GNSS RFI power density	-54.0	dBc/MHz	Noise density rel. to carrier
GPS channel filter	-0.5	dBMHz	Convert to Prfi in GPS channel (Equiv. Rectangular noise BW = 924 kHz)
Antenna gain (toward GNSS user)	0.0	dBi	Quasi-omni antenna pattern
Equivalent Transmit EIRP in RFI	-30.5	dBm	
Space loss	-76.6	dB	range = 100 meters
Shielding/Shadowing	0.0	dB	
GNSS user ant. gain @ RFI	-5.0	dBi	
Received Carrier Power (MES)	-112.1	dBm	
Received Carrier Power (GPS)	-130.0	dBm	Min. specified value (ref. :GPS Signal spec.)
Effective C/I	-17.9	dB	C/I = -J/S
Required C/I	-24.0	dB	Max tolerable C/I for RFI BW > 100 kHz
Margin	6.1	dB	

Exhibit 3-2: Probability Functions Applied to Variable Elements of the Link Budget

<table>
<tr><th>Link Budget Element</th><th>Probability Function</th><th>Mean</th><th>Variance</th></tr>
<tr><td>MES xmt. power Δ (desired carrier)</td><td>
</td><td>0.714</td><td>4.311</td></tr>
<tr><td>GNSS antenna gain Δ</td><td>
</td><td>-1.25</td><td>6.021</td></tr>
<tr><td>GNSS antenna shadowing by airframe</td><td>
</td><td>-2.5</td><td>2.083</td></tr>
<tr><td>GPS signal level Δ</td><td>
</td><td>+1.5</td><td>0.75</td></tr>
</table>

variation in azimuth of less than 3 dB (this specification only applies at elevation angles of 5 degrees or more above the horizon). The nominal link budgets above were based on -5 dB gain. To account for the range of variation in this parameter, a uniform density function over (-5.5 dB, 3 dB) was selected.

c. GNSS antenna shadowing by airframe and additional below-horizon gain loss. Since the MES emissions will enter the GNSS antenna from below the horizon, it is expected that the airframe will introduce some limited amount of shielding or shadowing. The GNSS antenna gain might also fall off rapidly below the horizon even in the absence of airframe shadowing. The range of variation in this parameter is not known at this time; a uniform density function over (-5dB, 0 dB) was hypothesized.

d. GPS signal level. The nominal link budgets were based on the minimum specified signal level for GPS as stated in the GPS SPS Signal Specification; higher received power levels will typically be experienced by GNSS users. To account for this variation, a uniform density function on (0 dB, 3 dB) was hypothesized.

To capture these variable influences, a probabilistic link budget analysis was performed by determining the mean and variance of the sum of the variable influences. After accounting for the direction or polarity of each influence on link margin, the mean impact of all variable influences is an improvement in expected margin of 4.5 dB. However, the margin could vary as a function of these influences, with a standard deviation of 3.6 dB. The expected link margin of 6.1 + 4.5 = 10.6 dB is therefore 2.9 times larger than the standard deviation in the link budget of 3.6 dB. Assuming for this preliminary analysis that the sum of all variable link budget parameters leads to an approximately Gaussian distribution; this would indicate that a GNSS user operating 100 meters from a Globalstar MES might expect a roughly 0.2% chance of degraded operation. In this context, degraded operation implies that the GNSS receiver is processing one or more GPS signals at $J/S \geq 24$ dB (the ARINC Characteristic 743A-1 specification). Degraded operation does not necessarily imply a loss of GPS signal tracking, although such loss of tracking could occur under these conditions. For J/S ratios slightly above the specified value, one would expect the GNSS receiver to maintain tracking, but with somewhat increased jitter. This would translate into a position solution with somewhat increased error variance (although the effects of GPS Selective Availability (SA) would dominate in nondifferential operations).

This analysis is preliminary, and based on hypothesized density functions only. It ignores the likelihood that environmental blockages, which lead to increased transmit power by the MES, would also lead to increased path loss between the MES and the GNSS receiver. Further study of these factors may be warranted.

3.2 Link budget Analysis Relative to GLONASS signals

The minimum specified signal strength of a GLONASS signal at the Earth's surface is -135.5 dBm. The impact of an MES on such a signal depends on the GLONASS and MES channel assignments as well as the link budget parameters introduced previously relative to GPS. As illustrated previously in Exhibit 2-1, the MES out-of-band emissions include an IM "skirt" as well as a broadband noise floor. For MES-to-GLONASS frequency offsets of 4 MHz or less, the IM skirt will dominate. For larger frequency offsets, the broadband noise floor will dominate. Exhibit 3-3 tabulates the equivalent EIRP transmitted in a GLONASS channel as a function of MES channel assignment and GLONASS channel ID. These equivalent EIRPs can be processed through a standard link budget as was done previously for GPS.

Exhibit 3-4 presents the situation for broadband noise in unshadowed conditions. This link budget parallels the budget for GPS signals presented earlier in Exhibit 3-1. Key differences relative to

Exhibit 3-3: Total XMT RFI Power Level in GLONASS Channel (Nominal)

MES Operating in Channel #	Transmit Power Level (dBm) in GLONASS Channel																					
	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	22	23	24
1	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-32.4	-29.6	-26.8	-23.9	-30.9	-33.3	-33.5
2	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-32.8	-30.1	-24.8	-27.6	-30.4
3	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-8.5	-21.4	-24.2
4	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	20.6	20.1	4.1
5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-26.4	10.3	20.5
6	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-25.6	-23.8	-20.9
7	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-32.7	-29.9	-27.1
8	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.0
9	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5
10	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5
11	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5
12	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5
13	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5	-33.5